Beamline 2.0: The Fully Integrated Instrument

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and The James Franck Institute (JFI)
University of Chicago

ALIO INDUSTRIES True Nano™
The Industry Leader in True Nano-Precision Motion Systems

InSync, Inc.
An Optical Manufacturing Company

Co-Organizers:
Lahsen Assoufid, APS;
Dean R. Haeffner, APS;
John P. Quintana, APS)

Goals of the Workshop

- Reexamine the paradigm on which beamlines are designed and integrated.

- Examine the storage ring and beamline from the standpoint of complete integrated instruments from the particle beam through the final experimental setup.
  - Traditionally the shield wall represented a functional barrier between the beamline and the storage ring. It will be important to remove this barrier to allowing complex control of undulators and incorporation of real time storage ring information into the experiment.

- Explore future directions in state-of-the-art synchrotron radiation instrumentation technology.

9:00 – 9:30	**Michael Borland** (Accelerator Systems Division, Argonne National Laboratory) "Accelerator Considerations and the APS Upgrade"
9:30 – 10:00	**Efim Gluskin** (Accelerator Systems Division, Argonne National Laboratory) "Undulators at the APS: Current State and Future Plans"
10:00 – 10:30	*Coffee Break*
Session 2	
10:30 – 11:00	**Jean Vilain** (Newport Corporation) "Fine, Fast, Coordinated Motion and Its Control"
11:00 – 11:30	**Jon Kelly** (Instrument Design Technology, Ltd. UK) "The Trials and Tribulations of Double-Crystal Monochromator Design"
11:30 – 12:00	**Michael Landry** (California Institute of Technology) "LIGO: The Laser Interferometer Gravitational Wave Observatory"
12:00 – 1:30	*Lunch*
Session 3	
1:30 – 2:00	**Chris Jacobsen** (X-ray Science Division, Argonne National Laboratory) "Integrated Microscopes: Challenges from Optics to Nanopositioning to Cryo"
2:00 – 2:30	**Ivan Vartaniants** (HASYLAB, Deutsches Elektronen-Synchrotron) "Coherence Properties of Hard X-ray Synchrotron Sources and X-ray Free Electron Lasers"
2:30 – 3:00	**Lahsen Assoufid** (X-ray Science Division, Argonne National Laboratory) "Optics and Metrology Development at the APS"
3:00 – 3:30	**Kazuto Yamauchi** (Osaka University) "A Novel On-site Wavefront Correction Method for Ultimate Focusing of Hard X-Rays"
3:30 – 4:00	*Coffee Break*
Session 4	
4:00 – 4:30	**Jean Susini** (Instrumentation Services and Development Division, European Synchrotron Radiation Facility) "The ESRF Upgrade Programme: Challenges for Instrumentation"
4:30 – 5:00	**Nino Micelli** (X-ray Science Division, Argonne National Laboratory) "Beyond the APS Detector Pool: Detector Systems Evaluation, Characterization, and Integration"
5:00 – 5:30	**Mark Rivers** (Center for Advanced Radiation Sources, The University of Chicago) "High-Performance Data Acquisition and Beamline Control: Current Capabilities and Future Needs"

The Importance of the Beamline Instrument

- Pedro Montano:
  - Beamline instrumentation critical for the future success of the science at the APS. The DOE administration recognizes the importance of upgrading beamlines; this should be one of the central focuses of the APS upgrade.

- Gopal Shenoy:
  - Fresh ideas were central in making the APS the success it is today. The same spirit should be applied to upgrading the existing beamlines and the development of new one.

- For the next generation beamline (Beamline 2.0) we need to invent new instrumentation solutions and implement existing ones in more integrated, efficient and reliable ways.

Integrated Beamline Design

I. Proposed science and measurements

- Imaging and Coherence
- Extreme Conditions
- Ultrafast Dynamics / Short-Pulse X-ray Source
- Interfaces in Complex Systems
- High-Resolution Spectroscopy
- Proteins to Organisms
- Other outstanding science conducted at existing beamlines

II. Samples and their environments.

- Liquid cell
- Diamond anvils
- High pressure gas
- High temperature
- Cryogenic
- Laser stimulated
- UHV

III. Sample manipulation

- Rotation(s): single and multi axis with ultra low SOC
- Translation: ultra fine (nm) fast, stable and reproducible
- Fast “on the fly” scanning, minimizing overhead, with fast settling time
- Tight synchronization to other real time instruments and information.

IV. Sensors / x-ray detectors

- CCD
- PAD
- SDD
- APD
- Visible light spectrometry
- Online temperature / pressure measurements

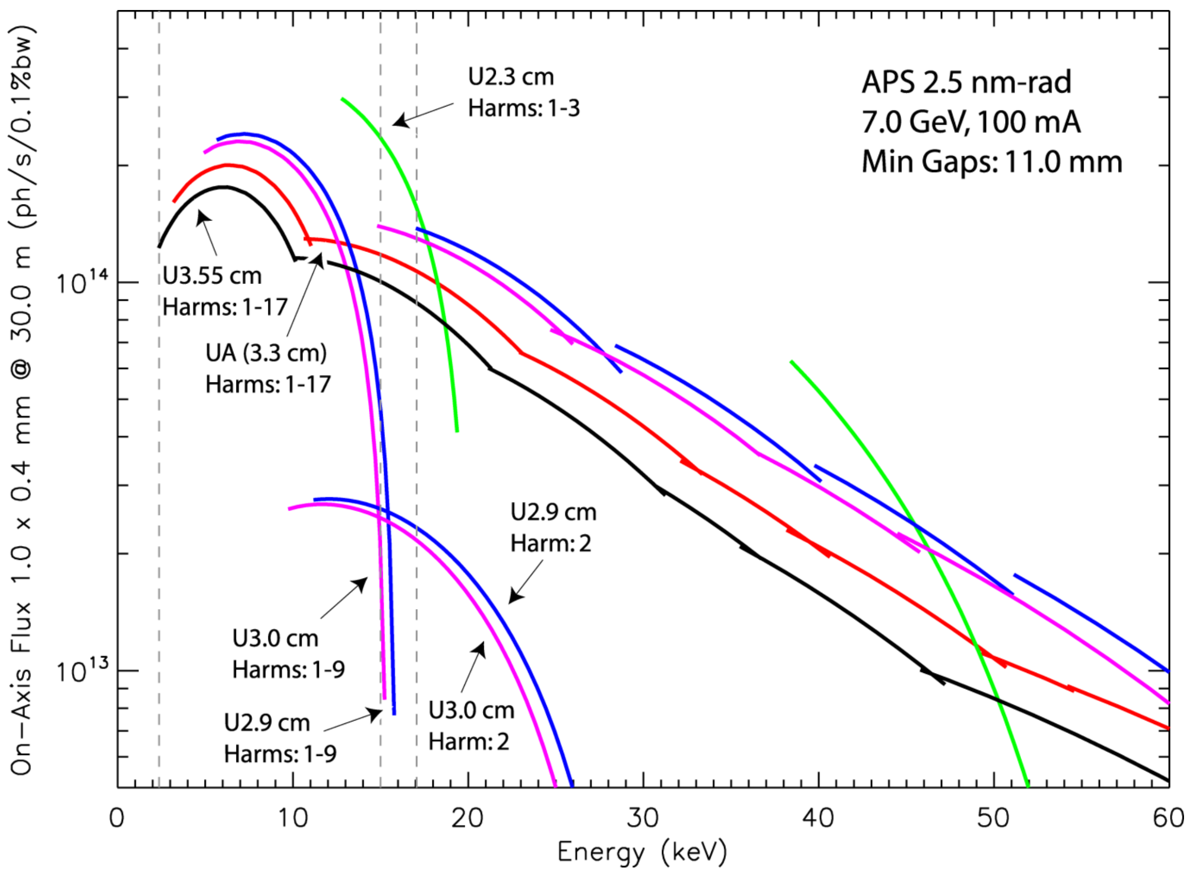
V. Source and optics requirements

- Source
  - Beta function
  - Long or short straight
  - Insertion device energy tuning range and polarization
- X-ray optics plan
  - Matching source phase space to the sample phase space acceptance
  - Maintain beam coherence
- Optics type
  - Mono
    - Energy range, offset
    - Diamond: water cooled
    - Si: LN2 cooled
  - Focusing
    - ZP
    - CRL
    - MLL
    - KB mirrors, fixed and figurable
    - Kinoform Lens

V. Source and optics requirements

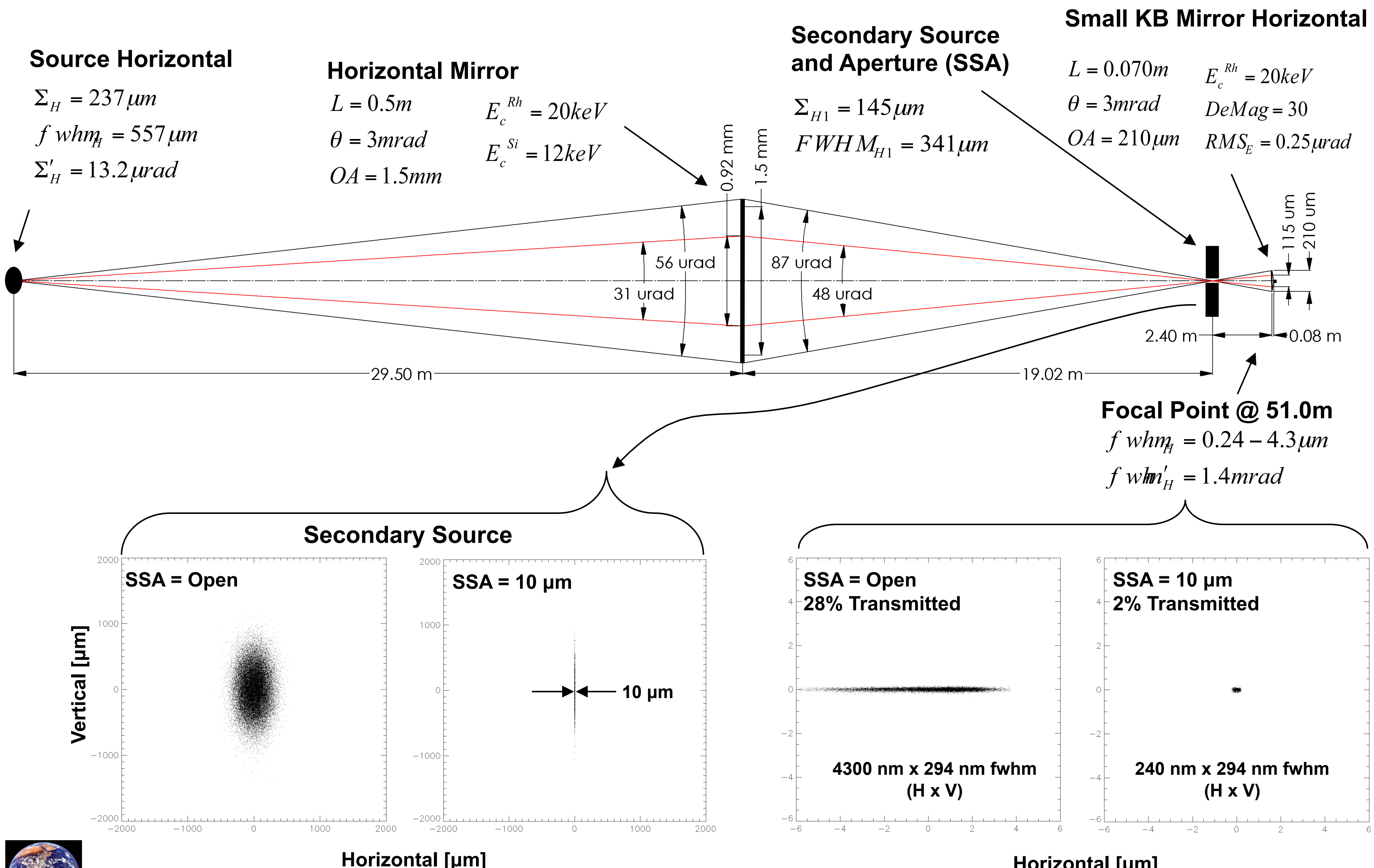
– Insertion device energy tuning range

On-axis flux tuning curves of different period lengths 2.3 cm, 2.9 cm, 3.0 cm, 3.55 cm vs. UA (3.3 cm), aperture: 1.0 (h) x 0.4 (v) mm @ 30 m



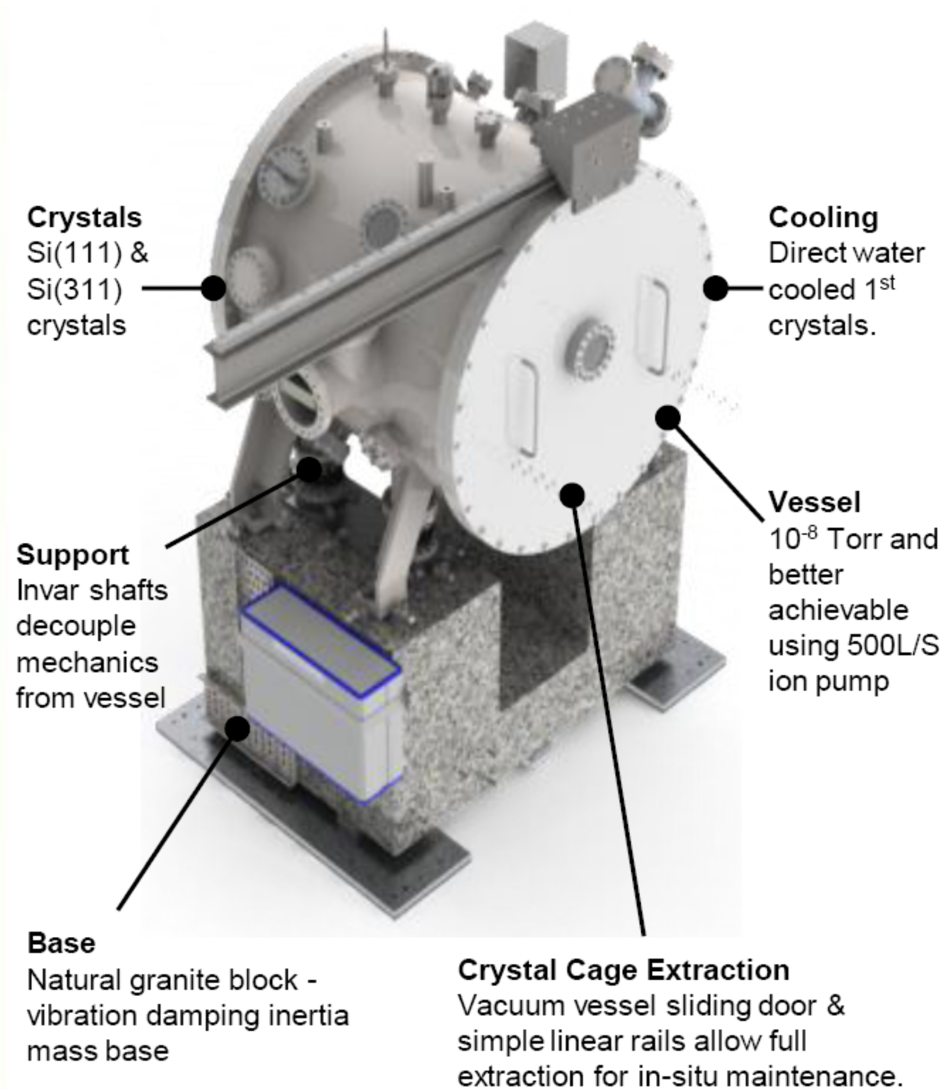
V. Source and optics requirements

– x-ray optics plan



V. Source and optics requirements

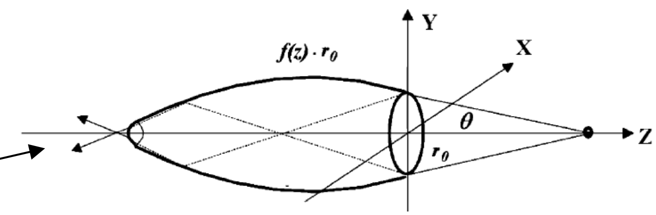
- x-ray optics plan
  - Mono
    - Energy range, offset
    - Diamond: water cooled
    - Si: LN2 cooled

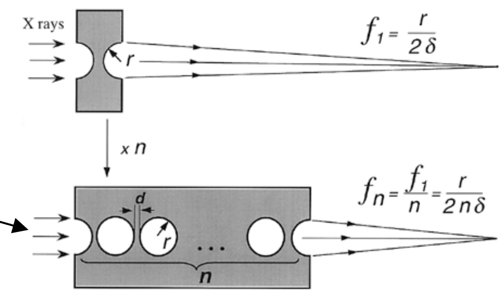


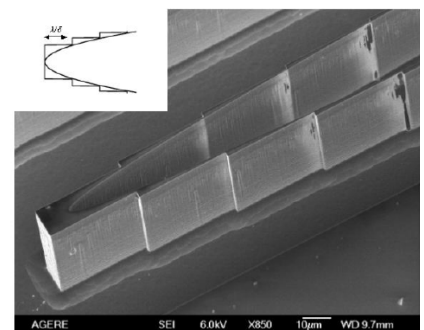
V. Source and optics requirements

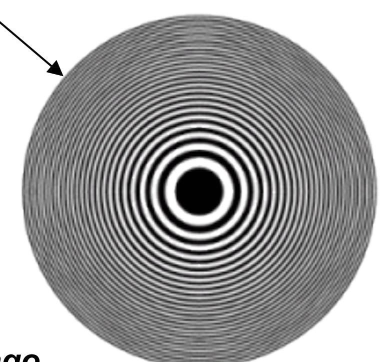
- x-ray optics plan
  - focusing
    - Tapered Capillaries
    - CRL
    - Kinoform Lens
    - ZP
    - MLL
    - KB, fixed and figurable

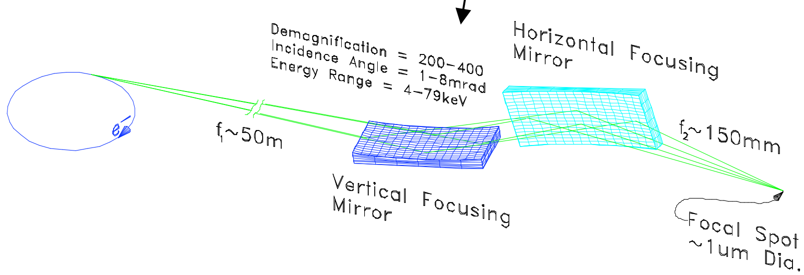
A. Liu, Y. Lin / Mathematics and Computers in Simulation 66 (2004) 577–584

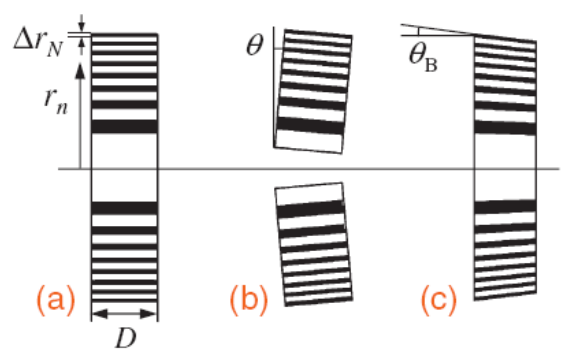










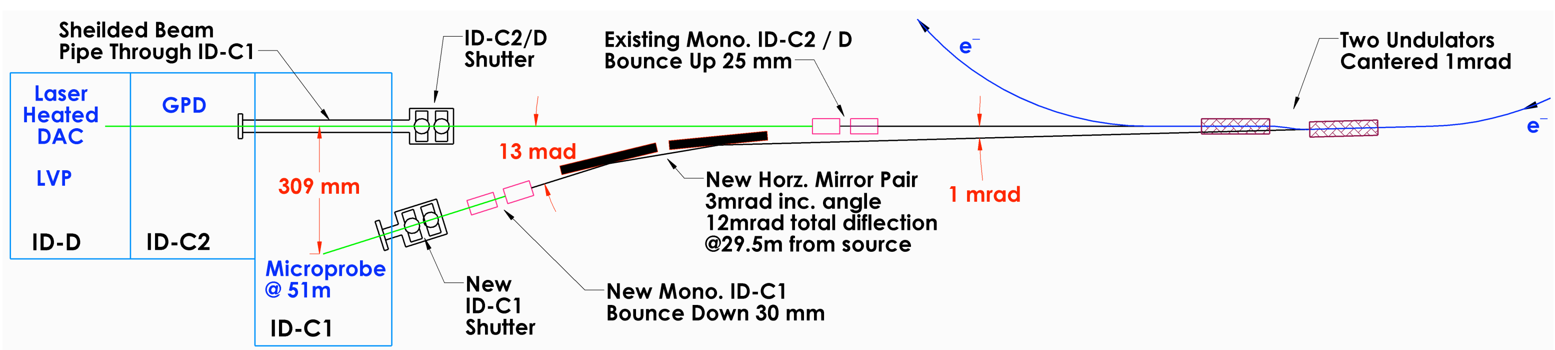


Many beamlines have optics plans and hardware dating back to 1995- 1998.

Need to look at other newer 3G facilities for ideas: what works, what doesn't?

Progress in Instrumentation from mid 90's to Today

- Greatly improved real time feedback of the orbit PUE and white beam BPMs
- Reduced emittance and reduce horizontal beta function
- Insertion devices
  - User controlled, scannable gap is routine
  - Long Undulators
  - Different periods (not just your mother's UA any more)
  - Elliptical
  - Multiple undulators in one straight section
    - Inline (operating at the same or different gaps)
    - Canted
  - Super Conducting
  - Cryogenically enhanced permanent magnets



Progress (continued)

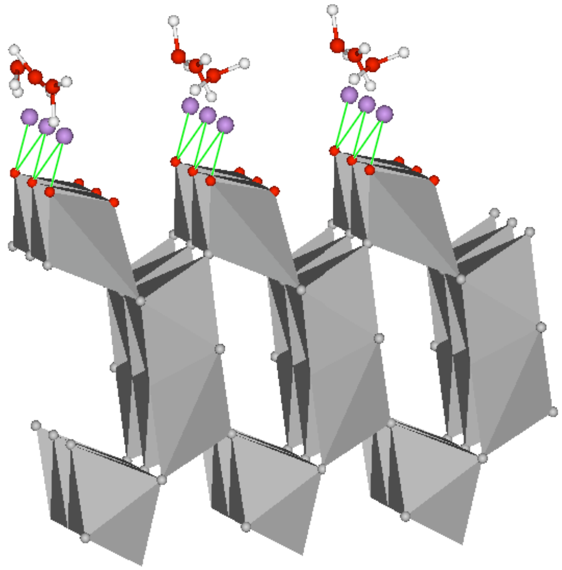
- Monochromator
  - Water-cooled Diamond
    - Diamond quality greatly improved
    - Low stress mounting
  - LN2-cooled Si
    - Improved mounting and cooling interface
    - Easily switched, multiple crystals, e.g., [111], [311]
    - LN2 flow vibration isolation, pressure insensitive
  - Greatly improved mechanism
    - Ultra high angular resolution well under one arcsec
    - Long second crystal with high flatness and low miscut
    - Only one in-vacuum linear motion needed: 1st and 2nd crystal gap

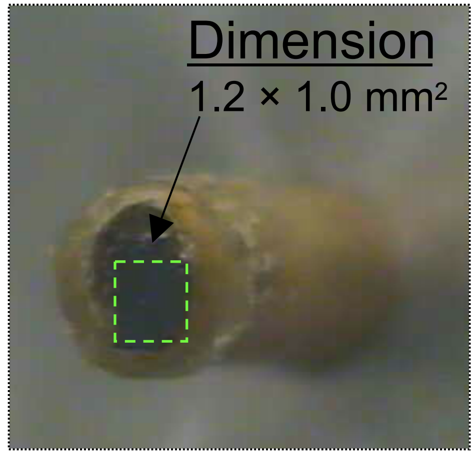
Progress (continued)

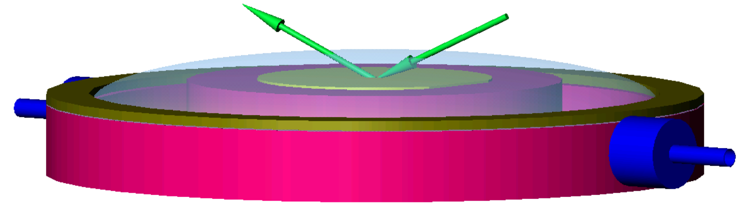
- Focusing optics
  - Mirrors
    - RMS slope error from 2-3 urad to 0.1 to 1 urad (1 m long)
    - RMS roughness from >3 A to <1 A
    - High stability benders
    - Long KB mirrors pairs
    - Pre-figured mirrors (fixed focal length) with RMS slope errors under 0.1 urad
    - FWHM from 1 micron to 150 nm and on long beamline 7 nm!
  - ZP
    - Difficult to acquire and focused to 300 nm FWHM previously, now routinely available and focusing to 50 nm FWHM or better
  - CLR
    - Did not exist. Now widely used particularly at high energy with one micron focus
  - MML
    - Did not exist. Now capable of focusing to 15 nm
  - Kinoform Lens
    - Did not exist. Now performance predicted down to 20 nm FWHM

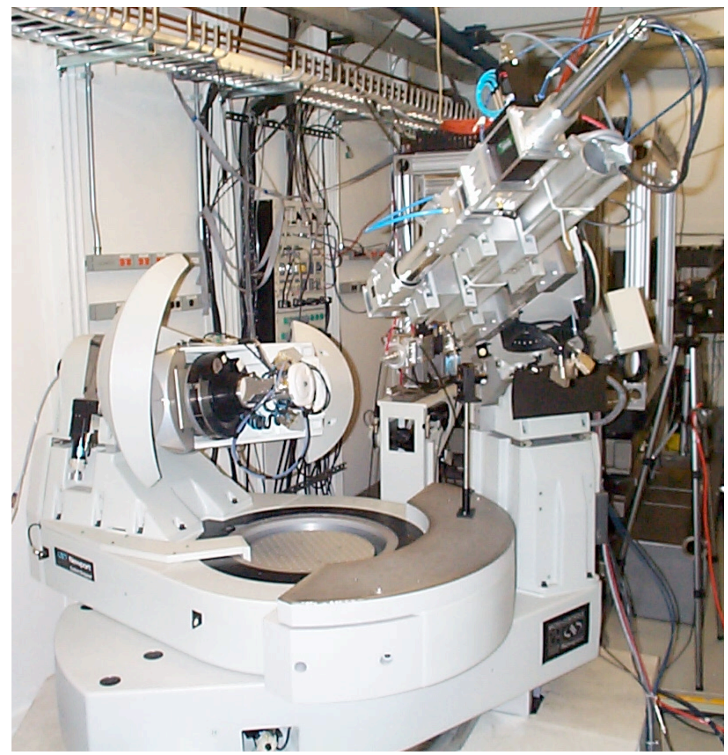
Example of a fully integrated beamline experiment

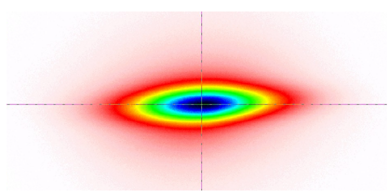
Arsenic sorption on Goethite(100)

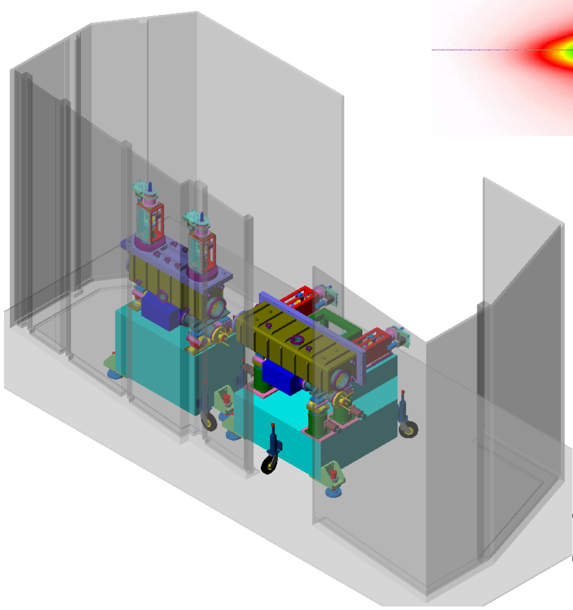






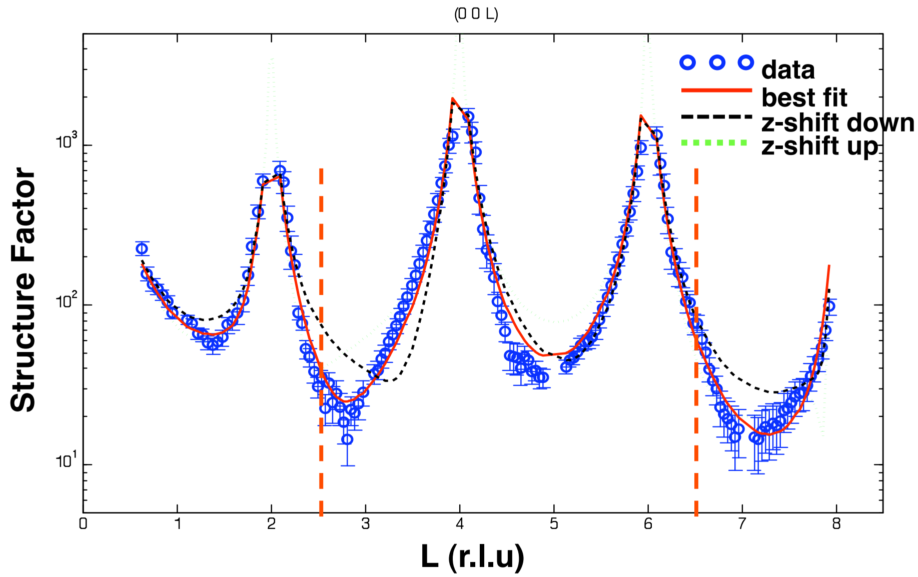


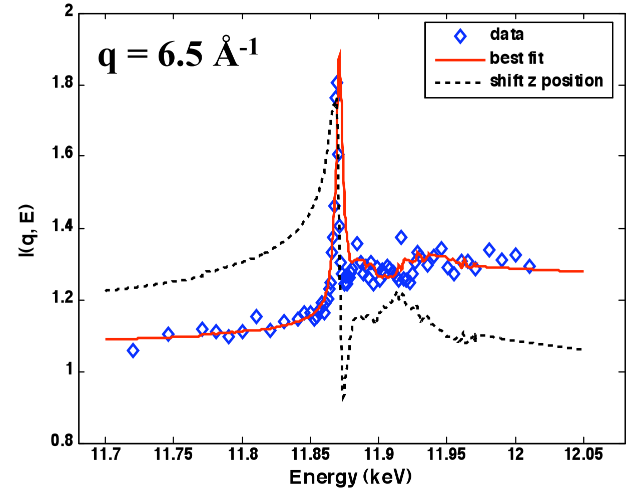


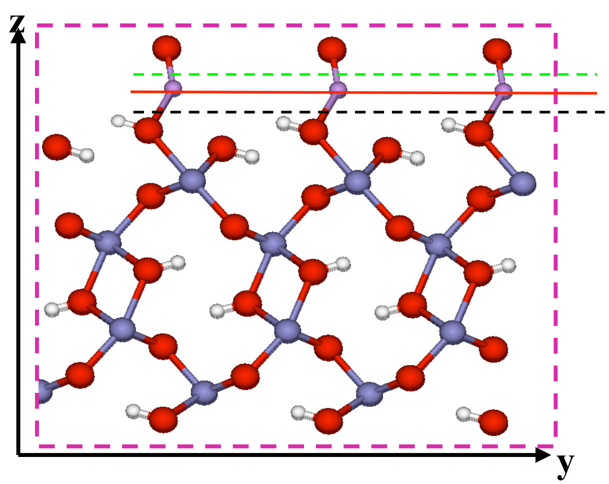


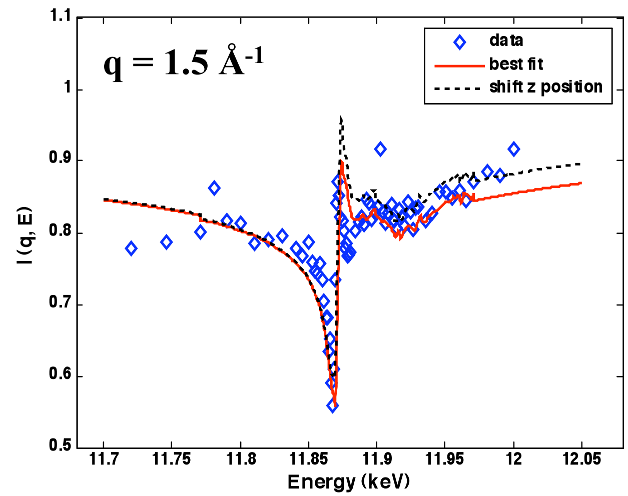
Example (continued)

Resonant Anomalous X-ray Scattering RAXS from CTR









Example (continued)

- Endstation
  - Small single crystal sample in a liquid cell (with remote solution control) mounted to a multi-axis diffractometer
  - A scriptable control program
    - Understands complex instruments like multi axis 2+2+kappa diffractometer and orientation matrix
  - On the fly rod scans (r-space scans),
  - On the fly energy scans at constant Q (all six diffractometer angles need to change i.e. like DAFS)
  - Fast and tight detector synchronized with instrument motion

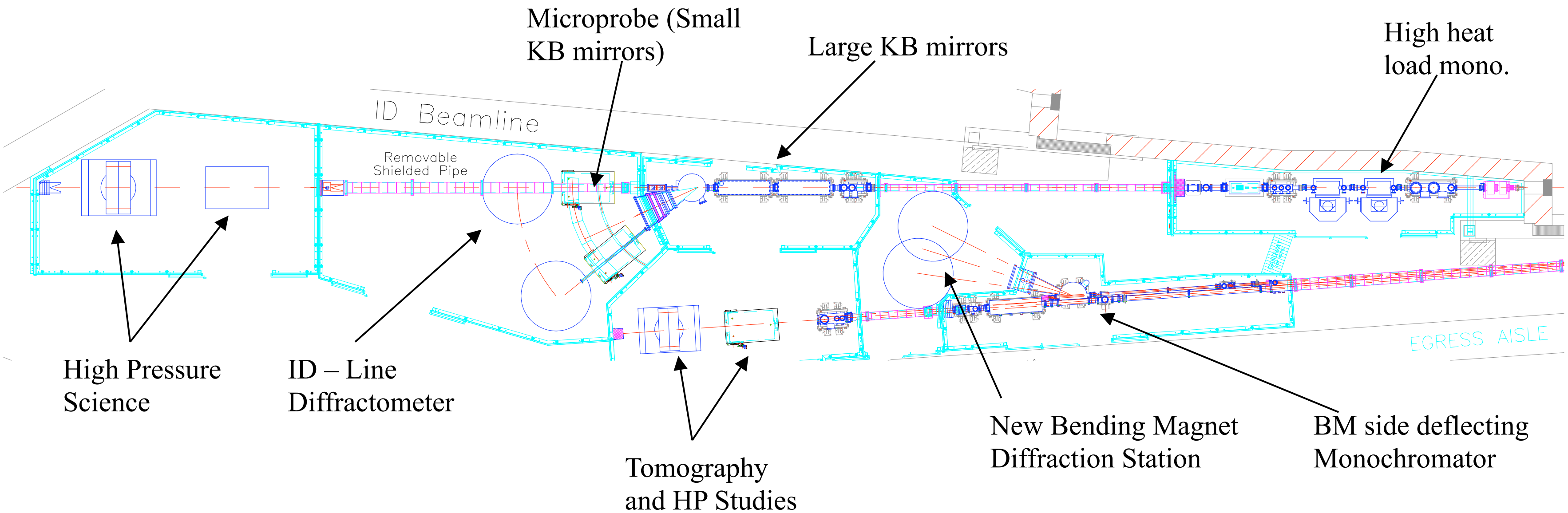
Example (continued)

- Total beamline on the fly motion synchronization (i.e. Energy as a motor)
  - Six diffractometer axes
  - Two monochromator axes
    - Rotation angle
    - 2nd crystal offset
  - Undulator Gap
    - On the fly non-linear gap control

Example (continued)

- Keeping the beam center on the sample
  - BPMs to control orbit searing as a function of gap
  - Beam stabilization onto the sample over time and energy
    - Feedback needs to remain locked in real time during an on-the-fly energy scan.

Getting the Most Out of Your Real Estate



Four Experimental End Stations

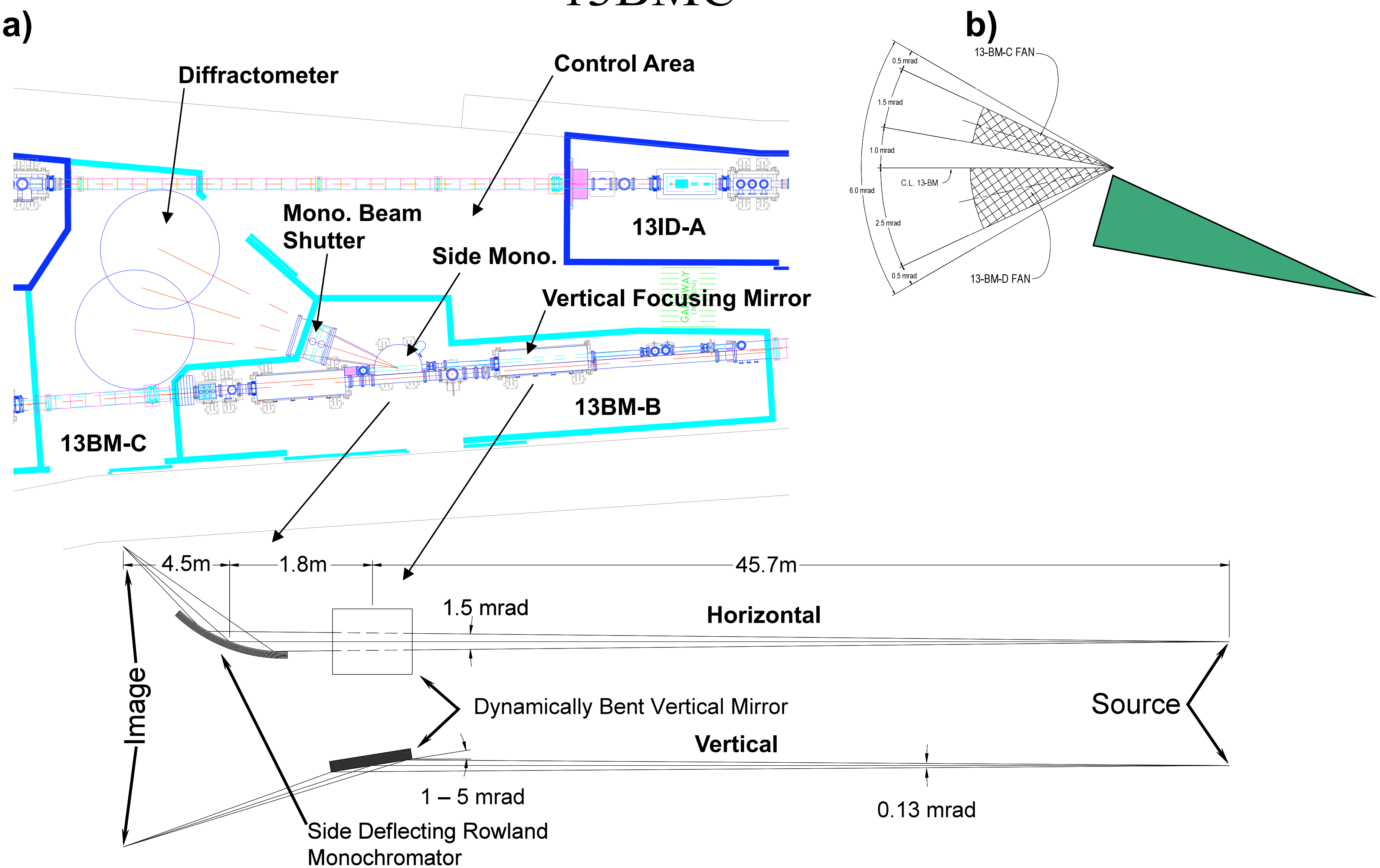
BMC
- *DAC diffraction*
- *Surface Scattering*

BMD
- *Tomography*
- *DAC + Brillouin*
- *LVP 250 ton press*
- *XAS*

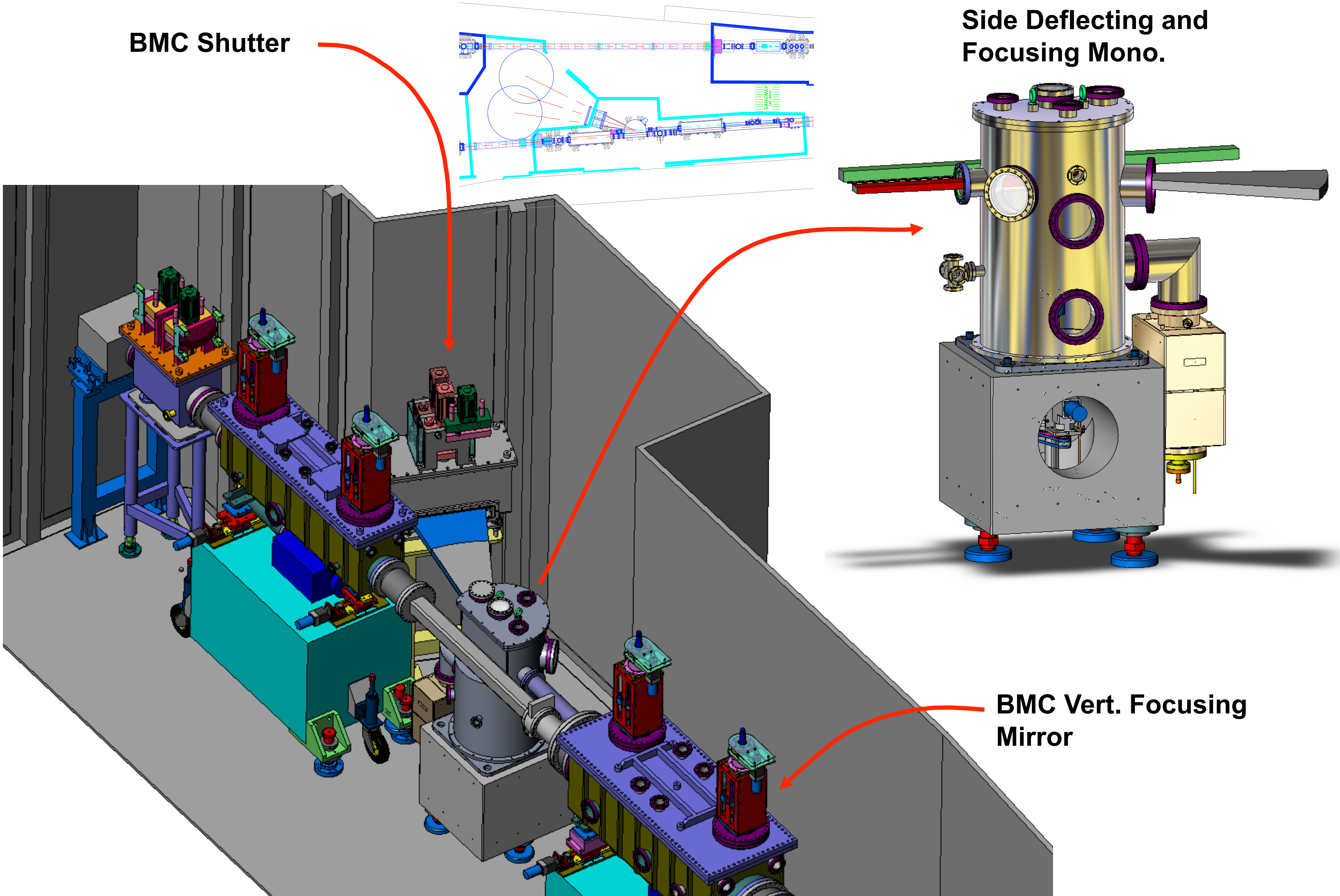
IDC
- *Microprobe*
- *Diffraction and scattering (Interface and Bulk)*
- *DAC X-ray Raman Scattering Spectroscopy*

IDD
- *Laser Heated DAC*
- *LVP 1000 ton press*

13BMC



a)
Diffractometer
Control Area
Mono. Beam
Shutter
Side Mono.
13ID-A
Vertical Focusing Mirror
13BM-B
13BM-C
b)
13-BM-C FAN
0.5 mrad
1.5 mrad
1.0 mrad
C.L. 13-BM
6.0 mrad
2.5 mrad
0.5 mrad
13-BM-D FAN
4.5m
1.8m
45.7m
1.5 mrad
Horizontal
Image
Dynamically Bent Vertical Mirror
Source
Vertical
1 – 5 mrad
0.13 mrad
Side Deflecting Rowland
Monochromator
c)


BMC Shutter
Side Deflecting and Focusing Mono.
BMC Vert. Focusing Mirror